ROLE OF WAVEFRONT OF LIGHT IN RALEIGH AND BRACE TYPE EXPERIMENTS

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ABSTRACT

Various experiments have been conducted to measure velocity of earth, to test length contraction and time dilation as stipulated by special theory of relativity. These experiments includes MMX, Kennedy- Thorndike experiment, Hammar experiment, Sagnac experiment and Raleigh and Brace experiment. All these experiments are based on wave nature of light. Wavefront of light plays very crucial role in these experiments. While interpreting the results of these experiments the behaviour of wavefront of light has not been considered resulting in to wrong conclusions.

The result of these experiments can be explained by classical mechanics satisfactorily if behaviour of light wavefront is considered. The length contraction and time dilation like phenomenon's are not required to explain these experiments. In the present article it is demonstrated how behaviour of wavefront of light effects the result of Raleigh and Brace experiment.

KEYWORDS: Wavefront, Mirror, Ray of light

EXPERIMENT

A simple diagram of Raleigh and Brace experiment is drawn to understand the theoretical derivations of time of flight of light rays in different directions.

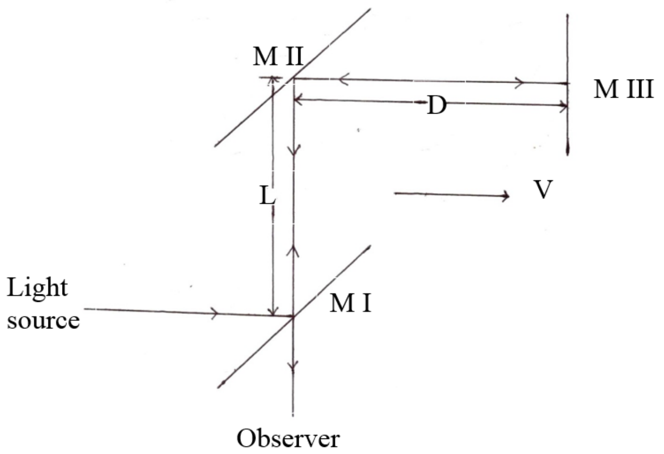


Fig I: Simplified diagram of Raleigh and Brace experiment

Let distance between mirror M I and M II be L and distance between mirror M II and M III be D. Let the velocity of light be c and velocity of earth be v

I Let us discuss when earth is moving in horizontal direction

Let a ray of light strikes at point A above the mid point O of M I at a distance of vt_1 where vt_1 is a distance by which earth moves in time t_1 with velocity v and time t_1 is time taken by ray of light to reach at mirror M II after striking at A on M I. By the time t_1 light reaches at M II the mirror M II would have moved a distance of vt_1 in right direction so the light ray will travel a distance of $(L-vt_1)$

Light ray will strike at mid point O on M II as shown in Fig II below

Therefore time $t_1 = \frac{L-vt_1}{c}$

$$ct_1 = L - vt_1$$

$$ct_1 + vt_1 = L$$

$$t_1 = \frac{L}{c+v}$$

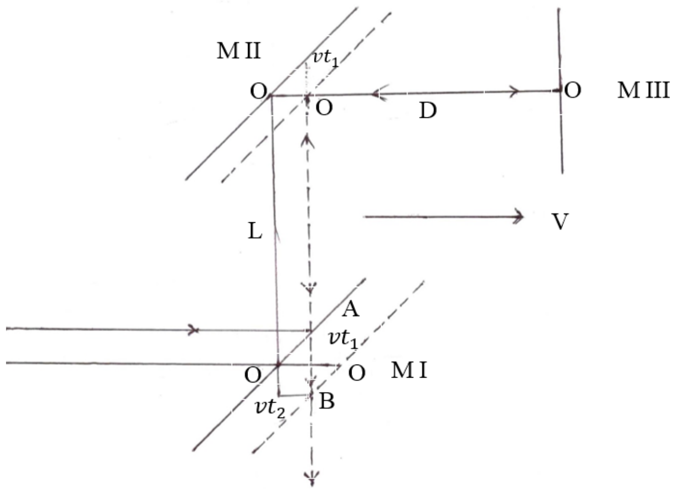


Fig II

This ray after reflection from M II will go towards a plane mirror M III it will travel the distance D with velocity (c-v), the time taken by the ray will be $\frac{D}{c-v}$. After reflection from M III it will return on M II at the same point O by taking time $\frac{D}{c+v}$. Now this ray after reflection from M II will return at mirror M I but by the time t_2 it returns at M I the mirror M I would have moved towards right direction by factor vt_2 and this ray will strike at point B on M I below the mid point O by factor vt_2 travelling the distance of $(L+vt_2)$ with velocity c

therefore time $t_2 = \frac{L+vt_2}{c}$

$$ct_2 = L + v\,t_2$$

$$ct_2 - v\,t_2 = L$$

$$t_2\,(c - v) = L$$

$$t_2 = \frac{L}{c-v}$$

Let total time taken by ray of light for its to and fro journey be t.

therefore $t = \frac{L-vt_1}{c} + \frac{D}{c-v} + \frac{D}{c+v} + \frac{L+vt_2}{c}$

$$= \frac{L-\frac{v\times L}{c+v}}{c} + \frac{D}{c-v} + \frac{D}{c+v} + \frac{L+\frac{v\times L}{c-v}}{c}$$ (By putting the value of t_1 and t_2)

$$= \frac{Lc+Lv-Lv}{c\,(c+v)} + \frac{D}{c-v} + \frac{D}{c+v} + \frac{Lc+Lv-Lv}{c\,(c-v)}$$

$$= \frac{Lc}{c\,(c+v)} + \frac{Lc}{c\,(c-v)} + \frac{D}{c-v} + \frac{D}{c+v}$$

$$= \frac{L}{c+v} + \frac{L}{c-v} + \frac{D}{c-v} + \frac{D}{c+v}$$

$$= \frac{Lc-Lv+Lc+Lv}{(c+v)\,(c-v)} + \frac{Dc+Dv+Dc-Dv}{(c+v)\,(c-v)}$$

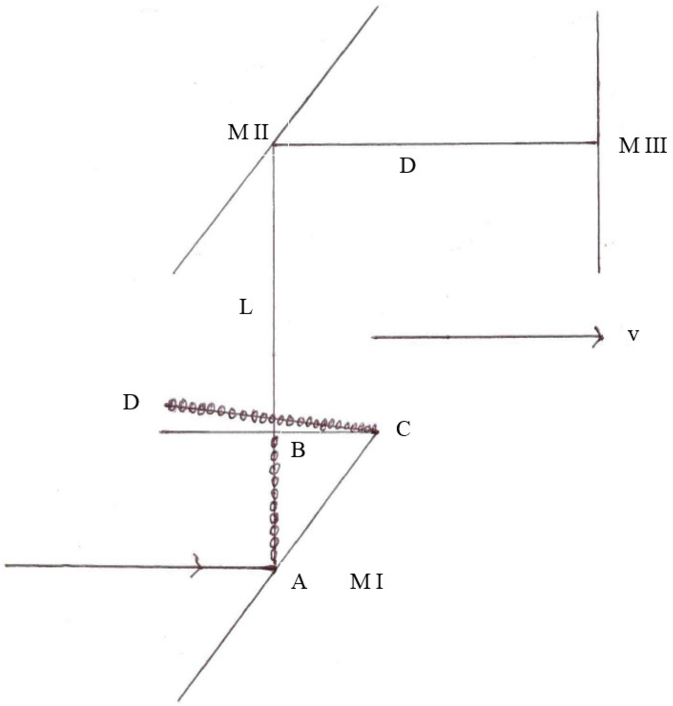
$$= \frac{2\,Lc}{c^2-v^2} + \frac{2\,Dc}{c^2-v^2}$$

$$\boxed{t = \frac{2L}{c}\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{2D}{c}\frac{1}{\left(1-\frac{v^2}{c^2}\right)}} \quad \text{——— I}$$

The ray of light striking at a point A above the mid point O on mirror M I at a distance of vt_1 will return on M I at a point B below mid point O by distance of vt_2. Now let us demonstrate how wavefront of light plays its role and how it compensates.

Role of WaveFront

Before proceeding further the nature of wavefront should be understood. A plane wavefront of light after reflection from a moving mirror with the velocity of earth will not remain plane, instead of it, it will be inclined at some angle directely proportional to the velocity of moving mirror, while deriving the time this behaviour of wavefront should be kept in view, the movement of same point of wavefront is to be considered so that correct time of flight may be derived. The reflected wavefront on a moving mirror is shown in Fig III below.



(i) Incident wavefront AB
(ii) Reflected wavefront CD

Fig III

Let a point of wavefront strikes at O on the mirror M I. Let us track the other point of same wavefront lying at a distance of $(vt_1 + vt_2)$ from O which will be able to return at the same point O after its journey to and fro. This point of wavefront will strike at a point A after taking time $\left(\frac{vt_1+vt_2}{c-v}\right)$ as shown in Fig IV below. After striking at A it will go towards M II and by the time t_1 it reaches at M II the mirror would have moved by factor vt_1

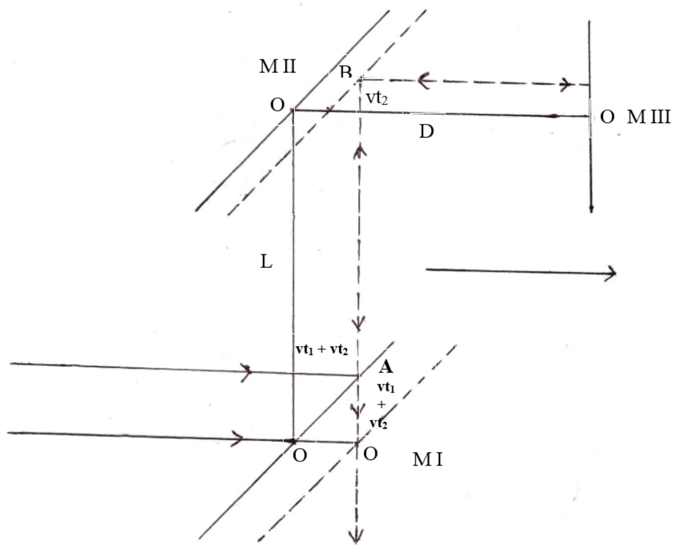


Fig IV

this ray will travel a distance of $L-vt_1$ with velocity c hence time t_1 will

be $\frac{L - vt_1}{c} = ct_1$

$c\,t_1 + vt_1 = L$

$t_1\,(c + v) = L$

$t_1 = \frac{L}{C+v}$

This ray will strike at B above mid point O on mirror M II at a distance of vt_2 after reflection it will go towards M III and will travel the distance $(D – vt_2)$ with velocity $(c – v)$ and return at M II at the same point by travelling same distance $(D – vt_2)$ with velocity $(c + v)$. There after this ray will return at M I at mid point O and it will travel a distance of $(L + vt_2)$ with velocity c

Therefore time $t_2 = \frac{L + vt_2}{c}$

$$ct_2 = L + v\,t_2$$

$$ct_2 - v\,t_2 = L$$

$$t_2\,(c - v) = L$$

$$t_2 = \frac{L}{c-v}$$

Let the total time of flight be t.

$$t = \frac{vt_1+vt_2}{c-v} + \frac{L-vt_1}{c} + \frac{L+vt_2}{c} + \frac{D-vt_2}{c-v} + \frac{D-vt_2}{c+v}$$

$$= \frac{vt_1+vt_2}{c-v} + \frac{L-vt_1}{c} + \frac{L+vt_2}{c} + \frac{Dc-c\,vt_2+Dv-v^2\,t_2+Dc-c\,vt_2-Dv+v^2\,t_2}{(c+v)(c-v)}$$

$$= \frac{\frac{v\times L}{c+v}+\frac{v\times L}{c-v}}{c-v} + \frac{L-\frac{v\times L}{c+v}}{c} + \frac{L+\frac{v\times L}{c-v}}{c} + \frac{2Dc-2\frac{cv\times L}{c-v}}{(c+v)\,(c-v)}$$ (By putting the value of t_1 and t_2)

$$= \frac{Lvc-Lv^2+Lvc+Lv^2}{(c+v)\,(c-v)\,(c-v)} + \frac{Lc+Lv-Lv}{c\,(c+v)} + \frac{Lc-Lv+Lv}{c\,(c-v)} + \frac{2Dc^2-2Dcv-2Lvc}{(c+v)\,(c-v)\,(c-v)}$$

$$= \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)} + \frac{L}{c+v} + \frac{L}{c-v} + \frac{2\,Dc\,(c-v)}{(c^2-v^2)\,(c-v)} - \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)}$$

$$= \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)} - \frac{Lc-Lv+Lc+Lv}{c^2-v^2} + \frac{2\,D\,c}{c^2-v^2} - \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)}$$

$$= \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)} - \frac{2\,L\,vc}{(c^2-v^2)\,(c-v)} + \frac{2\,L\,c}{c^2-v^2} + \frac{2\,Dc}{c^2-v^2}$$

$$= \frac{2\,L\,c}{c^2-v^2} + \frac{2\,Dc}{c^2-v^2}$$

$$= \frac{2\,L\,c}{c^2\left(1-\frac{v^2}{c^2}\right)} + \frac{2\,Dc}{c^2\left(1-\frac{v^2}{c^2}\right)}$$

$$\boxed{t = \frac{2L}{c}\,\frac{1}{1-\frac{v^2}{c^2}} + \frac{2D}{c}\,\frac{1}{1-\frac{v^2}{c^2}}} \qquad \text{——— II}$$

As evident from equation No I and II the part of same wavefront of light will be able to reach at the same point O travelling to and fro taking the same time, it reflects the crucial role of wavefront of light in the optical experiments conducted on wave nature of light.

II Let us discuss what will be the position when earth is moving in verical direction or the instrument is rotated at 90^0 angle as shown in Fig. V

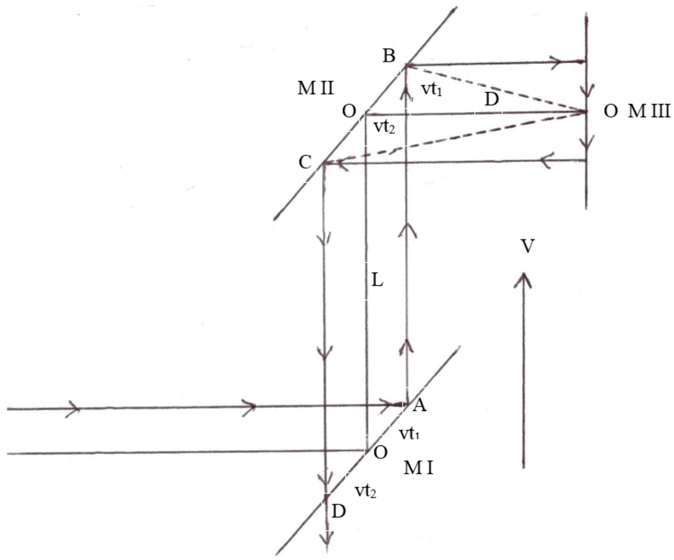


Fig V

Let a ray of light strikes at a point A above the mid point O by factor vt_1 where vt_1 is a distance moved by earth in time t_1 by which ray of light reaches from M II to M III. The ray of light striking at A goes towards M II, after reflection it will travel the distance L with velocity $(c – v)$ and time taken will be $\frac{L}{c-v}$it will strike at a point B above mid point O on M II by factor vt_1. Thereafter it will go towards M III by travelling distance $D – vt_1$ with velocity c

therefore $t_1 = \frac{D-vt_1}{c}$

$$ct_1 + vt_1 = D$$

$$t_1(c + v) = D$$

$$t_1 = \frac{D}{c+v}$$

This part of wavefront will strike at mid point O on M III, after reflection the ray will return towards M II and by the time it returns at M II the mirror would have moved by factor vt_2 hence this part of wavefront will strike at C on M II and will travel a distance of $D + vt_2$ with velocity c

therefore $t_2 = \frac{D + vt_2}{c}$

$$ct_2 - vt_2 = D$$

$$t_2\,(c - v) = D$$

$$t_2 = \frac{D}{c-v}$$

After reflection from M II the ray will return at M I at point D below mid point by factor vt_2 travelling the distance L by velocity (c + v) taking time $\frac{L}{c+v}$

Let us calculate total time of flight to and fro

$$t = \frac{L}{c-v} + \frac{D-vt_1}{c} + \frac{D+vt_2}{c} + \frac{L}{c+v}$$

$$= \frac{L}{c-v} + \frac{L}{c+v} + \frac{D-\frac{v\times D}{c+v}}{c} + \frac{D+\frac{v\times D}{c-v}}{c} \quad \text{(By putting the value of } t_1 \text{ and } t_2\text{)}$$

$$= \frac{Lc+Lv+Lc-Lv}{(c+v)\,(c-v)} + \frac{Dc+Dv-Dv}{c\,(c+v)} + \frac{Dc-Dv+Dv}{c\,(c-v)}$$

$$= \frac{2L\,c}{c^2-v^2} + \frac{D}{c+v} + \frac{D}{c-v}$$

$$= \frac{2L\,c}{c^2-v^2} + \frac{Dc-Dv+Dc+Dv}{c^2-v^2} = \frac{2L\,c}{c^2-v^2} + \frac{2D\,c}{c^2-v^2}$$

$$\boxed{t = \frac{2L}{c}\,\frac{1}{1-\frac{v^2}{c^2}} + \frac{2D}{c}\,\frac{1}{1-\frac{v^2}{c^2}}} \text{ ——— I}$$

As derived above the particular point of wavefront of light striking at A above the mid point O by factor vt_1 on M I and returns at D below mid point by factor vt_2 is taking same time

Let us discuss what will be the time of flight of ray when it will start from the plane line EF crossing the mid point O and returning at the same line EF. The pathway is shown in Fig VI below.

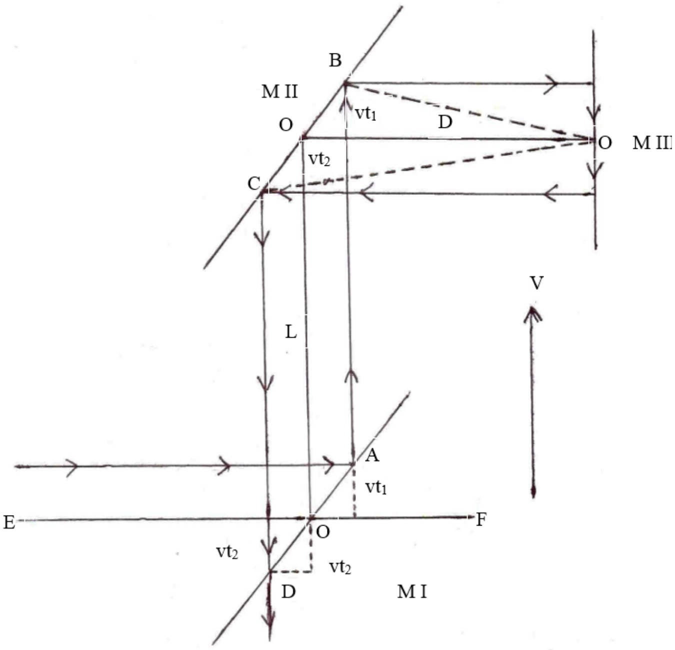


Fig VI

To arrive at the time taken we have to add the time $\frac{vt_1}{c-v}$ and deduct the additional time of going down by distance vt_2 at D which is $\frac{vt_2}{c+v}$. There fore time t will be as under

$$t = \frac{2L}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{2D}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{vt_1}{c-v} - \frac{vt_2}{c+v}$$

$$= \frac{2L}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{2D}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{v\times\frac{D}{c+v}}{c-v} - \frac{v\times\frac{D}{c-v}}{c+v} \quad \text{(By putting the value of } t_1 \text{ and } t_2\text{)}$$

$$= \frac{2L}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{2D}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{vD}{c^2-v^2} - \frac{vD}{c^2-v^2}$$

$$\boxed{t = \frac{2L}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)} + \frac{2D}{c}\,\frac{1}{\left(1-\frac{v^2}{c^2}\right)}} \text{ ——— II}$$

Time of flight of light wavefront starting from the plane EF and returning at the same plane will remain same. It is evident that there is no effect of motion of earth in any directon due to behaviour of wavefront of light that is the reason behind the null result of Raleigh and Brace experiment.

CONCLUSION

The wavefront of light is playing a crucial role in null results of various experiments which are conducted on wave nature of light but the effect of wavefront of light has not been considered by physicists while interpreting null results of MMX, Hammar experiment, kennedy – Thorndike experiment, Raleigh and Brace experiment etc. Wavefront of light plays its role in LIGO and VIRGO also and further research will reveal the contribution of wavefront of light in these experiments which are based on wave nature of light.

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